Simulated African Swine Fever (ASF) virus detection in Italy: average numbers of farms and pigs under restriction

Giorgia Baiocchi[1*], Andrea Marcon[1], Olivia Bessi[2], Luigi Ruocco[2] and Vittorio Guberti[1]

[1]*Dipartimento di fauna selvatica, Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA), Ozzano dell'Emilia (BO), Italy.*
[2]*Direzione Generale sanità animale e farmaci veterinari, Ufficio 3, Sanità animale e gestione operativa del Centro Nazionale di lotta ed emergenza contro le malattie animali, Unità Centrale di Crisi del Ministero della Salute, Roma (RM), Italy.*

[*]*Corresponding author at: Dipartimento di fauna selvatica, Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA), Ozzano dell'Emilia (BO), Italy. E-mail: giorgia.baiocchi86@gmail.com.*

Veterinaria Italiana 2022, **58** (3), 295-305. doi: 10.12834/VetIt.2651.16696.2
Accepted: 02.12.2021 | Available on line: 31.12.2022

Keywords
Farms under restriction,
Kept and wild pigs,
Simulation.

Summary
African swine fever is a devastating contagious viral disease of kept and wild porcine animals that will challenge the Veterinary Services involved in its eradication. Nowadays, ASF represents one of the biggest challenges for the pig sector at a global level. Following a number of simulated virus random introductions, the paper estimates the average number of farms (including their type) and animals that will be under restriction, and finally the average distance of infected farms from the nearest rendering plant. The study includes data referring to 101,032 farms with 9,322,819 pigs which are available in the Italian National Database (BDN). The simulations consider 5 different biogeographic regions with their own domestic pig distribution, breeding systems, and wild boar presence. Following an index case in a farm, and in the worst-case scenario, in the 10 km radius of the restriction area, there will be: 2,636 farms in South Italy; 470,216 animals in Po Valley; 147 km in Central Italy is the longest mean distance from the infected farm to the nearest rendering plant.

Introduction

African Swine Fever (ASF) is a contagious haemorrhagic fever affecting both domesticated and wild pigs belonging to the species *Sus scrofa*. It is one of the most complex and economically devastating diseases, causing a major socio-economic impact in affected countries. ASF is an internationally notifiable disease whose presence strongly affects internal and international trades of live pigs and pig products, increasing market price volatility, disrupting usual trade flows and applying selective pressure on small pig farms, changing the structure of the pig farming system in the EU in the last decade (Bellini 2021). Introduced in Georgia in 2007, it spreads north and then west through Europe and east through Asia, with cases occurring mainly in domestic pigs in Asia (Vergne *et al.* 2020) and wild boars in Europe (EFSA 2019). In September 2020, the ASF virus (ASFV) reached the wild boar population in Eastern Germany on the border with Poland (Sauter-Louis *et al.* 2021). In Central and Western Europe, the virus has wild boar as its main epidemiological reservoir, while in the Balkans, the involvement of the Backyard farms sector plays a key role in the local maintenance of ASFV (Bellini *et al.* 2021).

In the EU, following an outbreak in domestic pigs, a Protection zone (circular, 3 km radius) and a Surveillance zone (ring-shaped, 7 km radius) are established, creating a restriction area of 10 km radius around the infected farm/holding [Commission Delegated Regulation (EU) 2020/687[1]]. During outbreak management, several actions are required by legislation (e.g. prohibition of animal and product movements, stamping-out and disposal of pigs, disinfection of the farm and premises) and the number of farms and pigs involved influences the effort required. In the best-case scenario, only one

[1] European Commission 2019. Commission Delegated Regulation of 17 December 2019 supplementing Regulation (EU) No. 429/2016 of the European Parliament and the Council, as regards rules for the prevention and control of certain listed diseases. (EU 687/2020). *Off J*, **L 174**, 03/06/2020, Art.21 par.1 and Annex V.

holding will be infected and all pigs will be stamped and disposed of safely, usually in a disposal facility [Commission Delegated Regulation (EU) 2020/687[2]]. However, the census of all pigs and pig holdings within the restriction zone must still be carried out, as well as the implementation of additional biosecurity measures [Commission Implementing Regulation (EU) 605/2021[3]] and a surveillance program to prevent or detect any secondary outbreaks at an early stage. The shortest duration of the restrictions is 15 days for the Protection zone (with an additional period of 15 days for surveillance measures in the Protection zone), and 30 days for the Surveillance zone, to be counted after the mandatory disinfection of holdings and premises. The restriction measures may last longer when the virus is detected in any other location/site of relevance. The Competent Authority may determine a different duration of the restricted zone on a case by case basis, taking into account factors influencing the risk of disease spread (e.g. category A disease transmitted by vectors, Commission Implementing Regulation 2018/1882[4]) [Commission Delegated Regulation (EU) 2020/687[5]].

In case of detection of ASFV in wild boars, legislation [Regulation (EU) 2016/429[6] and Commission Delegated Regulation (EU) 2020/687[7]] requires the establishment of an Infected area, possibly including a Core area (where the virus was detected) whose size is defined according to the local landscape and distribution of wild boars − the average size of the smallest wild boar Infected areas in the EU (Czech Republic, Belgium, Brandenburg in September 2020) is about 1,000 km^2. Within the Infected area, all wild boars found dead or hunted must be tested and − if positive for ASF − safely disposed of (SANTE/7113 2015), while movements of domestic pigs are allowed under veterinary supervision. Census of pigs and pig farms is mandatory in the Infected area, as well as the implementation of additional biosecurity measures and surveillance schemes. In the absence of *Ornithodorus* spp, restrictions will last for 12 months after the last positive result for ASFV or specific antibodies in a wild boar (OIE - Terrestrial Animal Code, 2019[8]), or until the operational expert group recommends lifting the measures based on epidemiological information [Regulation (EU) 2016/429[9] and Commission Delegated Regulation (EU) 2020/687[10]].

Commission Implementing Decision 2014/709/EU of 9 October defined a regionalisation approach in 4 different zones, reduced to 3 with the entry into force of EU Regulation 2016/429 based on Article 71, and implemented by EU Regulation 605/2021[11]. These measures relate to the movement of pigs, their products and by-products, including their trade and intra-EU market rules, depending on the presence of the virus and related risks.

The presence of ASF implies a huge effort for veterinary services, depending on the number of farms and pigs involved, the distribution and abundance of wild boars, and the availability of disposal facilities where pigs or wild boars can be safely disposed of.

One of the most pressing arguments to support ASF eradication in pigs is the economic loss that the presence of the infection will cause. The greatest economic loss will come from the block on both domestic and international trade in pork and pork products from the infected area; some third-country trading partners may ban the whole country regardless of the geographical distribution of the virus. At a local level, eradication measures impose the block on animal movements and production in the restricted area, with the possibility of derogation for specific cases, which will affect not only pig farms, but all the commercial activities related to pig farming (e.g.

[2] European Commission 2019. Commission Delegated Regulation of 17 December 2019 supplementing Regulation (EU) No. 429/2016 of the European Parliament and the Council, as regards rules for the prevention and control of certain listed diseases. (EU 687/2020). *Off J*, **L 174**, 03/06/2020, Art. 22 par. 3.

[3] European Commission 2021. Commission Implementing Regulation of 7 April 2021 laying down special control measures for African swine fever. (EU 605/2021). *Off J*, **L 129**, 15/04/2021, Art. 16 and Annex II.

[4] European Commission 2018. Commission Implementing Regulation of 3 December 2018 on the application of certain disease prevention and control rules to categories of listed diseases and establishing a list of species and groups of species posing a considerable risk for the spread of those listed diseases. (EU 1882/2018). *Off J*, **L 308**, 04/012/2018, Annex table referred to in Art. 2.

[5] European Commission 2019. Commission Delegated Regulation of 17 December 2019 supplementing Regulation (EU) No. 429/2016 of the European Parliament and the Council, as regards rules for the prevention and control of certain listed diseases. (EU 687/2020). *Off J*, **L 174**, 03/06/2020, Art 39 and Annex X, Art. 55-56 and Annex XI, Art.58.

[6] European Parliament and Council 2016. Regulation of 9 March 2016 on transmissible animal diseases and amending and repealing certain acts in the area of animal health ('Animal Health Law'). (EU 429/2016). *Off J*, **L 84**, 31/03/2016, Art. 43 par.2 d) iii) and Art. 70.

[7] European Commission 2019. Commission Delegated Regulation of 17 December 2019 supplementing Regulation (EU) No. 429/2016 of the European Parliament and the Council, as regards rules for the prevention and control of certain listed diseases. (EU 687/2020). *Off J*, **L 174**, 03/06/2020, Art.63 and Art. 66.

[8] https://www.oie.int/en/what-we-do/standards/codes-and-manuals/terrestrial-code-online-access/?id=169&L=1&htmfile=chapitre_asf.htm.

[9] European Parliament and Council 2016. Regulation of 9 March 2016 on transmissible animal diseases and amending and repealing certain acts in the area of animal health ('Animal Health Law'). (EU 429/2016). *Off J*, **L 84**, 31/03/2016, Art. 31-35 and Art. 70.

[10] European Commission 2019. Commission Delegated Regulation of 17 December 2019 supplementing Regulation (EU) No. 429/2016 of the European Parliament and the Council, as regards rules for the prevention and control of certain listed diseases. (EU 687/2020). *Off J*, **L 174**, 03/06/2020, Art. 67.

[11] European Commission 2021. Commission Implementing Regulation of 7 April 2021 laying down special control measures for African swine fever. (EU 605/2021). *Off J*, **L 129**, 15/04/2021.

slaughter, transport, feed production) causing a knock-on effect on the economy. In addition, the trade ban that invariably will follow the epidemic will cause a surplus of pig meat and products on the national territory, leading to a collapse in prices that will affect the whole national pig and pork market. The situation would be further aggravated if the virus were to be detected in wild boars, both because the restriction area is wider − thus involving more farms and pigs − and because the restriction on farmed animals will last at least one year according to OIE rules in order to regain the disease-free status (Terrestrial Animal Health Code, Art. 15.1.4 2b[12]). This stricter regulation emerges from the difficulty of monitoring the disease in wildlife, so even if all farms in the area are ASF-free, the disease could still spread through the wildlife population and could return to farmed pigs in the area (e.g. Oļševskis *et al.* 2016, Oļševskis *et al.* 2020, Franzoni *et al.* 2020). Compared to the above, this was found to be applicable in those contexts with free-ranging pigs, as the interaction between these pigs and wild boars increases the risk of ASF outbreaks and the efforts needed to eradicate the disease in those areas (Franzoni *et al.* 2020, Tao *et al.* 2020).

The aim of this article is to outline - using two sets of simulations - the challenges that the local veterinary service will face in case of detection of ASF in pigs or wild boars in Italy. We quantified the average number and type of farms and reared pigs that will be restricted, as well as the average distance to the nearest rendering plants following the detection of the virus in kept or wild pigs. The simulations consider 5 different areas combining Italian biogeographic regions with domestic pig distribution, farming systems and an approximation for wild boars distribution.

Finally, it must be emphasised that, although this work was theorised at the end of 2021, the subsequent arrival of African swine fever in wild boar in January 2022 in the mountains between Piedmont and Liguria and in May of the same year first within Rome's Grande Raccordo Anulare (GRA) and then in the mountains of Rieti, made it clear that a quantitative approach - albeit in probabilistic terms - is indispensable to have an idea of the effort required to manage an outbreak of ASF; the number of flocks and animals to be surveyed and planned for slaughter, transport management; rendering capacities including rendering plants location, are all activities that often turn out to be the true criticalities that the Veterinary Services have to face in the various phases of outbreak management and that perhaps do not receive adequate attention in the preparatory phase of response to epidemics.

[12] https://www.oie.int/en/what-we-do/standards/codes-and-manuals/terrestrial-code-online-access/?id=169&L=1&htmfile=chapitre_asf.htm.

Methods

Study area

Our study area is the whole Italian territory, except Sardinia, which was excluded because ASF has been endemic in the island since the 1970s. Italy was subdivided into 5 roughly identified macro-areas (Figure 1), based on different environmental characteristics (e.g. Alps), the density of pig farms and the most common types of farming.

The Alps macro-area was defined according to the Alpine Convention (map downloaded from http://webgis.alpconv.org/, accessed 19 October 2019). The Po Valley macro-area was identified as the area below 150 m a.s.l., bounded by the Alps and the Apennines. The Northern Italy macro-area was defined as the area north of 44° N latitude (city of Massa, Tuscany) that is not included by the Alps and Po Valley macro-areas. The macro-area of Central Italy was defined as between 44° N latitude (town of Massa, Tuscany) and 41°.25 N latitude (town of Formia, Lazio), and the macro-area of Southern Italy includes the whole territory south of 41°.25 N latitude (town of Formia, Lazio). Wild boar distribution was defined as the area within a 3.5 km buffer around the forested area, while the Po Valley is wild boar free (Monaco *et al.* 2003). The forested

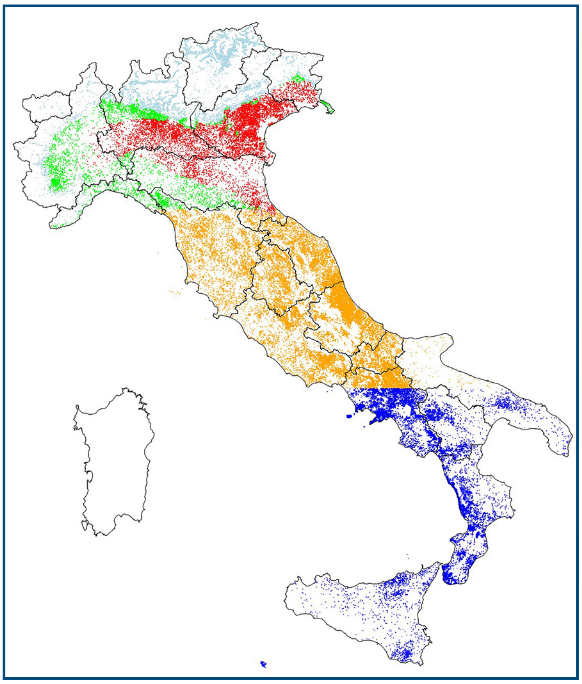

Figure 1. *Distribution of farms in Italy, divided into the five macro-areas considered.*

area of the country was ex-tracted from CORINE Land Cover 2018.

Data

National data on pig farms were extracted from the 'National Database (BDN) of the Identification and Registration System of Italy', which collects information on all farms and production chains related to animals on the national territory. The database contains accurate and up-to-date information on each establishment, including geographical coordinates, type of production, number of individuals, maximum capacity, movements, etc. These data allow us to depict an accurate scenario of what would happen if ASF arrived on a farm anywhere in the country. We selected farms that reported the geographical coordinates, the total number of pigs present or at least the capacity value (i.e. the maximum number of individuals allowed), and belonging to the following types: 'Breeders', 'Fatteners' and 'Backyards'. Breeders are large farms that house sows and boars for breeding purposes; Fatteners are large farms where animals are raised to slaughter size, and Backyards are small farms, with the same purpose as Fatteners farms, that can have a maximum of 4 pigs for home consumption, and are not allowed to move animals to other farms (SANTE/7113, 2015). In addition to pig farms, rendering plants (Figure 2) were considered to measure their distance from the centre of the outbreak.

Simulations

Pig farm density and type distribution varied widely among the five macro-areas, so analyses were run independently for each macro-area. We analysed the results of spatial simulations, where a randomly chosen pig farm was infected with ASF, which was assumed to be detected immediately, and the number of potentially affected pigs and pig farms was estimated from spatial and capacity data about pig farms (BDN). Simulation were iterated for each macro-area as follows. Around each randomly-selected virtually-infected farm, following EU regulations [Commission Delegated Regulation (EU) 2020/687[13]], a circular Protection zone was identified − with a radius of 3 km centred on the infected farm − where the strictest measures of the contingency plan are applied. In addition, a buffer Surveillance zone with a radius of 7 km was added, where less stringent measures are applied. Within each of these zones, we calculated the number of affected farms and the number of animals involved. As simulations were performed independently for each macro-area, pig farms included in one restriction zone but belonging to another macro-area were excluded from the analysis. This procedure was repeated 1,000 times for each macro-area, the results are reported as

[13] European Commission 2019. Commission Delegated Regulation of 17 December 2019 supplementing Regulation (EU) No. 429/2016 of the European Parliament and the Council, as regards rules for the prevention and control of certain listed diseases. (EU 687/2020). *Off J*, **L 174**, 03/06/2020, Art.21 par.1 and Annex V.

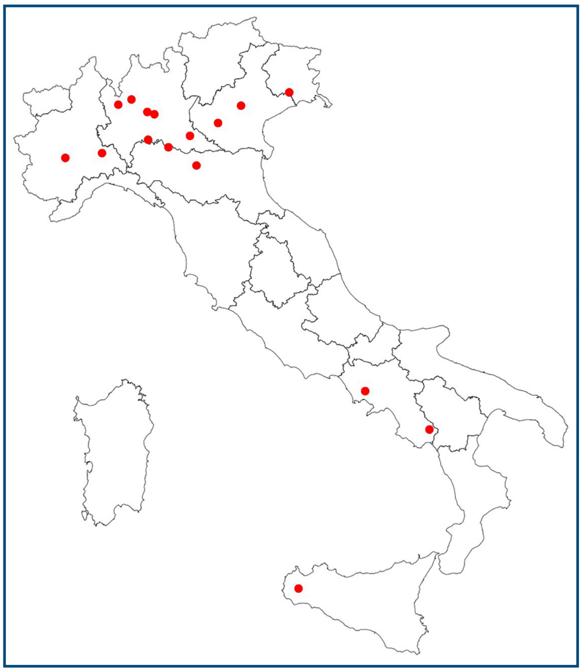

Figure 2. *Locations of rendering plants (red dots).*

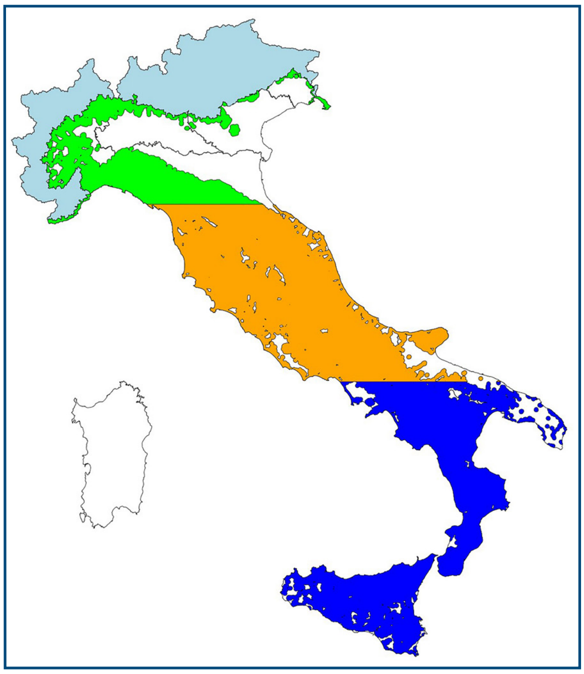

Figure 3. *Proxy of the distribution area of wild boar divided into the four macro-areas considered.* Sardinia was not included in this study.

mean value and range. In addition, we extracted from our simulation results the worst-case scenario, in terms of number of farms and number of pigs, that the whole restriction area (i.e. Protection zone and Surveillance zone) faced in a single simulation, for each macro-area. A second set of simulations was performed in the scenario where the ASF virus is detected in a wild boar population. Similar to the previous simulation procedure, a random point was identified within the wild boar territory (Figure 3) to represent the index case. Two buffer areas were drawn around this point to represent the two areas of different size where eradication measures will be implemented: a 200 km^2 circular area (about 8 km radius) and a 1,000 km^2 circular area (about 18 km radius) were created, mimicking respectively the Guidelines for CSF in wild boar (SANCO/7032 2010) and the average size of the smallest wild boar-infected EU areas (Czech Republic, Belgium, Brandenburg as of September 2020). For both areas (200 km^2 and 1,000 km^2), we calculated the number of affected pig farms and the number of animals involved, while wild boar population data were not considered. Again, simulations are performed for each macro-area independently and are repeated 1,000 times, and the results are reported as mean value and range of the number of farms and individuals located in the wild boar Infected area. The distances between the index case and the nearest rendering plant were also calculated, and are reported as mean and standard deviation.

Results

The national database reports that on the national territory − excluding Sardinia (n = 14601) − there are 128,463 pig farms; of these, 101,032 have the requirements to be included in our study, for a total population of 9,322,819 pigs. Observing the types of farms (Table I), we can see that the vast majority of farms are of the Backyard type (82.65%), followed by the Fatteners (10.99%), and the Breeders (6.37%). The farms are unevenly distributed among the macro-areas (Figure 4, Table II), with 11,348 farms in the Alps (11.23%-0.22 farms/km^2), 14,070 farms in the Po Valley (13.93%-0.37 farms/km^2), 6,313 farms in the North Italy (6.25%-0.21 farms/km^2), 41,487 farms in Central Italy (41.06%-0.48 farms/km^2), and 27,812 farms in the South Italy (27.53%-0.39 farms/km^2). The average density of farm types for each macro-area is visible in Table III. Moreover, the proportion of the type of farming varies among the macro-areas (Figure 5, Table II). Pigs are unevenly distributed among the farms (Table I), as the majority of pigs are found within Fattening farms (66.83%), followed by Breeding farms (30.51%), and Backyard farms (2.66%). This, of course, is due to the different number of pigs usually found within each type of farm: 2.97 ± 8.72 pigs on Backyard farms, 442.19 ± 1,571.36 pigs on Breeding farms, and 561.22 ± 1,384.34 pigs on Fatteners farms. Pig abundance differs among macro-areas (Figure 4, Table II) with 347,947 pigs in the Alps (3.73%), 6,310,791 pigs in the Po Valley (67.69%), 1,413,486 pigs in the North Italy (15.16%), 880,237 pigs in the Central Italy (9.44%) and 370,354 pigs in the South Italy (3.97%).

Table I. *Number of pig and pig farms in continental Italy for each type of farm considered, in brackets as a percentage of the total.* The last column reports the mean (and standard deviation) value of the number of pigs per farm for each type of farming.

Farm type	Farms	Pigs	Mean (SD)
Backyard	83,498 (82.7%)	248,017 (2.7%)	2.97 (8.72)
Fatteners	11,102 (11.0%)	6,230,628 (66.8%)	561.22 (1384.34)
Breeding	6,432 (6.4%)	2,844,174 (30.5%)	442.19 (1571.36)

Table II. *Total number of farms and pigs for each macro-area, both grouped and divided by farm type.* In brackets, the value is expressed as a percentage of the total.

Macro-area	Farms	Pigs	By type	farms	Pigs
Alps	11,348 (11.23%)	347,947 (3.73%)	Backyard	9,635	26,582
			Fatteners	1,370	198,033
			Breeding	343	123,332
Po Valley	14,070 (13.93%)	6,310,791 (67.69%)	Backyard	9,445	32,770
			Fatteners	3,855	4,390,782
			Breeding	770	1,887,238
North Italy	6,313 (6.25%)	1,413,486 (15.16%)	Backyard	4,174	12,996
			Fatteners	1,662	990,912
			Breeding	477	409,578
Central Italy	41,487 (41.06%)	880,237 (9.44%)	Backyard	35,943	114,529
			Fatteners	3,173	499,991
			Breeding	2,371	265,717
South Italy	27,812 (27.53%)	370,354 (3.97%)	Backyard	24,300	61,138
			Fatteners	1,042	150,910
			Breeding	2,470	158,306

Table III. *Density of holdings for each macro-area reported both as overall density and as density for each type of farm.* Densities are expressed as farms per square kilometre.

Macro-area	Farm density km^2			
	Overall	Backyard	Fatteners	Breeding
Alps	0.22	0.19	0.03	> 0.01
Po Valley	0.37	0.25	0.10	0.02
North Italy	0.21	0.14	0.06	0.02
Central Italy	0.48	0.41	0.04	0.03
South Italy	0.39	0.34	0.01	0.04

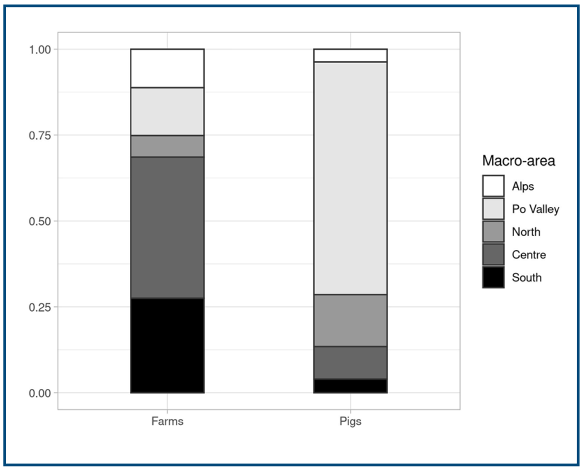

Figure 4. *Distribution of farms and pigs among macro-areas.*

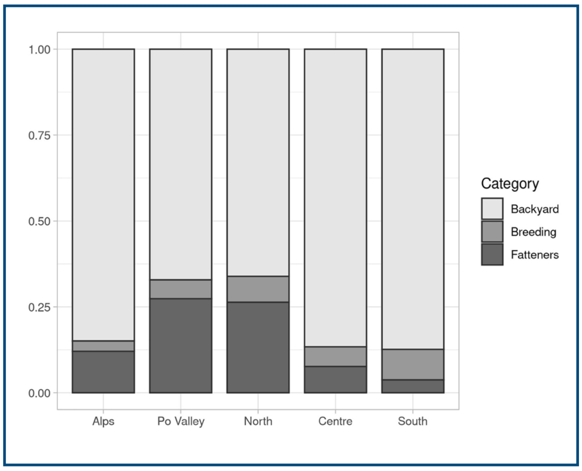

Figure 5. *Distribution of the type of farms among the macro-areas.*

Protection zone - 3 km radius

In the Alps, in the Protection zone, we found an average of 29.96 ± 23.16 farms (range 0-143), involving an average of 373.72 ± 1629.57 pigs (range 0-21,853, Figure 6, Table IV). In the Po Valley, we found an average of 21.55±15.60 farms (range 0-75), involving an average of 5,915.87 ± 10,715.67 pigs (range 0-69,712). In the North Italy, we found a mean of 14.75 ± 13.56 farms (range 0-65), which involved an average of 3,008.31 ± 8,425.68 pigs (range 0-67,388). In Central Italy, we found an average of 42.57±37.60 farms (range 0-305), which involved a mean of 592.90 ± 1,427.82 pigs (range 0-12,561). In the South Italy, we found an average of 91.60 ± 111.13 farms (range 0-686), which involved an average of 407.32 ± 627.20 pigs (range 0-10,523).

Surveillance zone - 7 km radius

In the Alps, in the Surveillance zone, we found an average of 155.88 ± 118.13 farms (range 0-483), with an average of 1,998.86 ± 4,929.25 pigs (range 0-49,212, Figure 7, Table IV). In the Po Valley, we found an average of 170.38 ± 109.13 farms (range 1-449), with an average of 55,089.75 ± 84,960.63 pigs (range 1-412,923). In the North Italy, we calculated an average of 91.53 ± 74.40 farms (range 0-308), with an average of 21,003.60 ± 49,753.84 pigs (range 2-289,964). In Central Italy, we encountered an average of 305.04 ± 233.29 farms (range 3-1,030), with an average of 4,602.49 ± 5,738.38 pigs (range 5-62,018). In the South Italy, we found an average of 465.06 ± 468.96 farms (range 1-2,416), with an average of 2,616.07 ± 2,455.85 pigs (range 2-17,654).

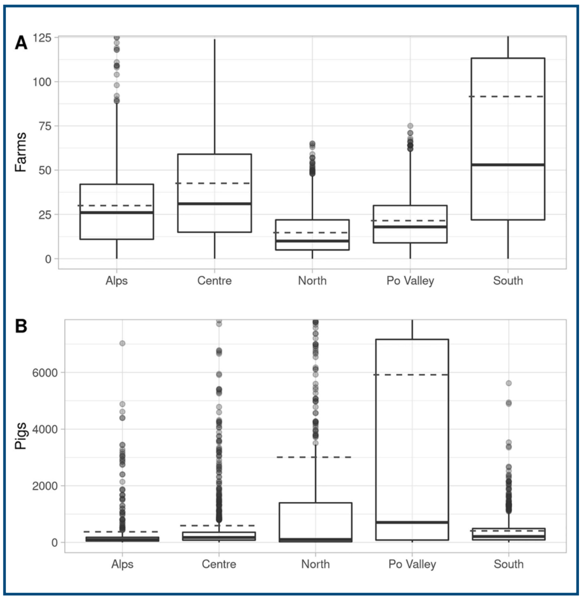

Figure 6. *Boxplots of the number of farms (**A**) and pigs (**B**) included in the Protection zone, for each macro-area.* The dashed lines show the mean values. Y-axes have been cropped to facilitate reading.

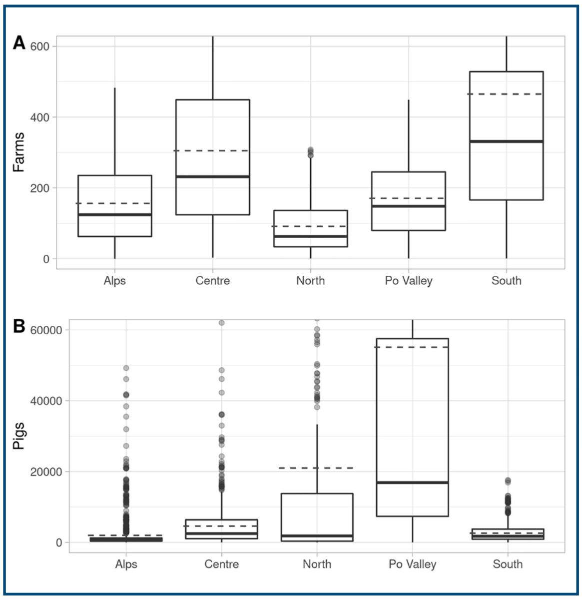

Figure 7. *Boxplots of the number of farms (**A**) and pigs (**B**) included in the Surveillance zone, for each macro-area.* Dashed lines show mean values. The Y-axis has been cropped to facilitate reading.

Veterinaria Italiana 2022, **58** (3), 295-305. doi: 10.12834/VetIt.2651.16696.2

Table IV. *Range and mean value (in brackets) of the number of farms and pigs included in the Infected and Surveillance areas for each macro-area.* The 'worst-case scenario' shows the highest number of farms or pigs involved in an outbreak in the whole restriction area (10 km radius) in a single simulation.

Macro-area	Protection zone		Surveillance zone		Worst case scenario	
	Farms	Pigs	Farms	Pigs	Farms	Pigs
Alps	29.96 ± 23.16 (0-143)	373.72 ± 1,629.57 (0-21,853)	155.88 ± 118.13 (0-483)	1,998.86 ± 4,929.25 (0-49,212)	546	62,251
Po Valley	21.55 ± 15.60 (0-75)	5,915.87 ± 10,715.67 (0-69,712)	170.38 ± 109.13 (1-449)	55,089.75 ± 84,960.63 (1-412,923)	503	470,216
North Italy	14.75 ± 13.56 (0-65)	3,008.31 ± 8,425.68 (0-67,388)	91.53 ± 74.40 (1-308)	21,003.60 ± 49,753.84 (2-289,964)	357	325,695
Central Italy	42.57 ± 37.60 (0-305)	592.90 ± 1,427.82 (0-12,561)	305.04 ± 233.29 (3-1,030)	4,602.49 ± 5,738.38 (5-62,018)	1,150	62,128
South Italy	91.60 ± 111.13 (0-686)	407.32 ± 627.20 (0-10,523)	465.06 ± 468.96 (1-2,416)	2,616.07 ± 2,455.85 (2-17,654)	2,636	17,775

Worst-case scenario

The extraction of the worst-case scenario returned a value of 546 farms and 62,251 pigs for the Alps, 503 farms and 470,216 pigs for the Po Valley, 357 farms and 325,695 pigs for the North Italy, 1,150 farms and 62,128 pigs for Central Italy, and 2,636 farms and 17,775 pigs for the South Italy (Table IV).

Wild boar Infected area - 200 km^2

In the Alps, in the 200 km^2 area we encountered an average of 41.20 ± 62.34 farms (range 0-455), with an average of 1,014.78 ± 3,707.31 pigs (range 0-48,720, Figure 8 and Table V). In the North Italy, we found a mean of 24.02 ± 33.82 farms (range 0-233), with a mean of 5,114.98 ± 17,436.50 pigs (range 0-177,294). In Central Italy, we encountered an average of 98.07 ± 119.34 farms (range 0-920), with an average of 1,760.82 ± 3,489.90 pigs (range 0-43,520). In the South Italy, we encountered an average of 66.80 ± 130.08 farms (range 0-1,273), with an average of 956.35 ± 1,693.44 pigs (range 0-17,993).

Wild boar Infected area - 1,000 km^2

In the Alps, in the 1,000 km^2 area we encountered an average of 188.15 ± 226.75 farms (range 0-1,290), with an average of 4,527.17 ± 10,294.15 pigs (range 0-94,559, Figure 9 and Table V). In the North Italy, we encountered an average of 104.97 ± 111.88 farms (range 0-594), with an average of 23,491.95 ± 71,065.63 pigs (range 0-581,867). In Central Italy, we encountered a

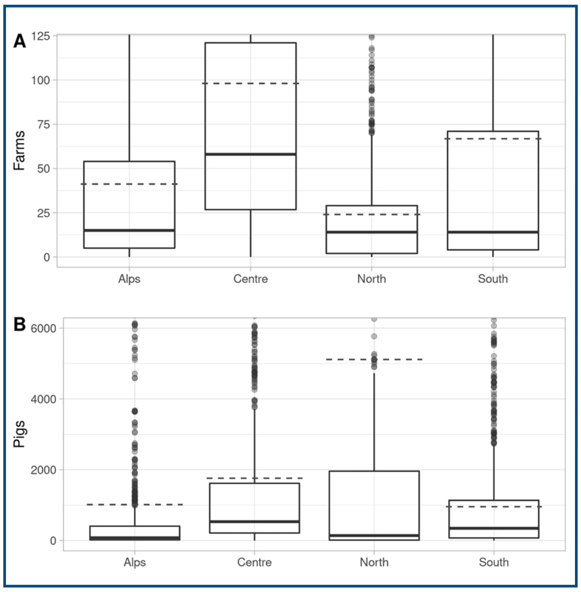

Figure 8. *Boxplots of the number of farms (**A**) and pigs (**B**) included in the Infected area of 200 km^2, for each macro-area.* The dashed lines show the mean values. The Y-axes have been cropped to facilitate reading.

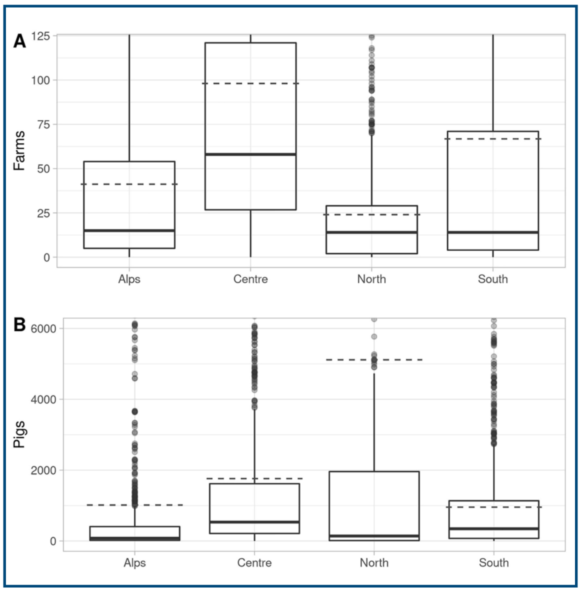

Figure 8. *Boxplots of the number of farms (**A**) and pigs (**B**) included in the Infected area of 200 km^2, for each macro-area.* The dashed lines show the mean values. The Y-axes have been cropped to facilitate reading.

Table V. *Average value and range (in brackets) of the number of farms and pigs included in the 200 km² and 1,000 km² areas for each macro-area.*

Macro-area	200 km² area		1,000 km² area	
	Farms	Pigs	Farms	Pigs
Alps	41.20 ± 62.34 (0-455)	1,014.78 ± 3,707.31 (0-48,720)	188.15 ± 226.75 (0-1,290)	4,527.17 ± 10,294.15 (0-94,559)
North Italy	24.02 ± 33.82 (0-233)	5,114.98 ± 17,436.50 (0-177,294)	104.97 ± 111.88 (0-594)	23,491.95 ± 71,065.63 (0-581,867)
Central Italy	98.07 ± 119.34 (0-920)	1,760.82 ± 3,489.90 (0-43,520)	488.35 ± 473.27 (0-2,801)	9,191.49 ± 13,044.88 (0-106,077)
South Italy	66.80 ± 130.08 (0-1,273)	956.35 ± 1,693.44 (0-17,993)	305.76 ± 473.11 (0-3,720)	4,677.08 ± 4,687.55 (0-30,939)

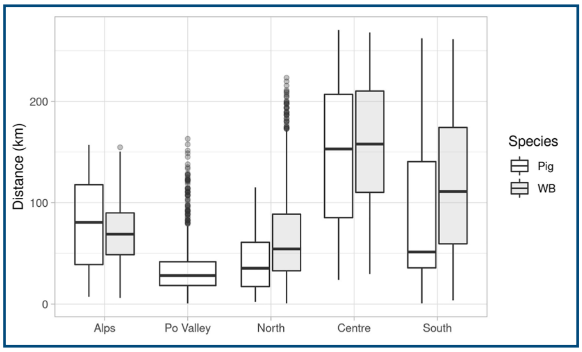

Figure 10. *Boxplots of the distance from the outbreak farm and wild boar case to the nearest rendering plant for each macro area.*

mean of 488.35 ± 473.27 farms (range 0-2,801), with a mean of 9,191.49 ± 13,044.88 pigs (range 0-106,077). In the South Italy, we encountered a mean of 305.76 ± 473.11 farms (range 0-3,720), with a mean of 4,677.08 ± 4,687.55 pigs (range 0-30,939).

Distance from rendering plants

The average distance of the outbreak farms from the nearest rendering plant is 78.68 ± 42.76 km (mean ± standard deviation, range 7.12-157.04 km) for the Alps, 34.28 ± 25.55 km (range 0.60-163.06 km) for the Po Valley, 40.34 ± 26.68 km (range 2.06-115.08 km) for the North Italy, 147.90 ± 67.59 km (range 23.79-270.43 km) for Central Italy, and 87.15 ± 72.37 km (range 0.71-262.17 km) for the South Italy (Figure 10). For the second set of simulations − case of ASF in a wild boar population − the average distance of the case location from the nearest processing plant is 71.59 ± 30.31 km (range 6.00-154,70 km) for the Alps, 65.65 ± 43.92 km (range 0.70-223.30 km) for North Italy, 158.98 ± 58.19 km (range 29.70-267.90 km) for Central Italy, and 117.61 ± 66.54 km (range 3.70-261.40 km) for the South Italy (Figure 10).

Discussion

The number of farms and pigs varies among macro-areas, with the highest number of farms in Central Italy and in the South Italy, which together represent about 70% of all farms, while the highest number of pigs is found in the Po Valley (about 70% of all pigs considered), followed by the North Italy (Figure 4). This divergence between farms and the number of pigs is due to the proportions of farm types present in each macro-area. The Po Valley and the North Italy have a higher number of pigs because these macro-areas have a higher proportion of Fatteners farms (around 25%), about twice as high as the other macro-areas (Figure 5). In our simulations, for the scenario with an outbreak of ASF, the South Italy had the highest average value of farms included in the restriction area, while the Po Valley had the highest number of pigs involved (Table IV). In the second set of simulations, for the scenario with a case of ASF in wild boars, Central Italy had the highest mean value of farms included and the Northern Italy had the highest number of pigs involved for both the 200 km² and 1,000 km² areas (Table V). Because the proportion of farm types affected by an outbreak likely reflects the distribution of farms present in a macro-area, we expect that a macro-area with a high number of Backyard farms faces a different logistical challenge than a macro-area where mostly large farms are present. From our results, we identified three potential scenarios that will follow the detection of ASF in Italy.

South Italy - high number of farms

Our simulations indicate that the South Italy will face the highest number of farms involved. The veterinary services will have to manage many Backyard farms, often family-owned, for which biosecurity requirements are not as stringent as for commercial farms, and they are often opened and closed on an annual basis, with frequent changes in location and number of pigs. In addition, family farms are geographically dispersed and their census requires a huge logistical effort (Regulation 2016/429[14]). Furthermore, a high density of

[14] European Parliament and Council 2016. Regulation of 9 March 2016 on transmissible animal diseases and amending and repealing certain acts in the area of animal health ('Animal Health Law'). (EU 429/2016). *Off J*, **L 84**, 31/03/2016, Art. 65-68..

Backyard farms increases the risk of secondary outbreaks, complicating and prolonging the eradication process. High density of pigs raised in low biosecurity farms is one of the high-risk factors for an outbreak, and further spread of the virus in both domestic and wild pig populations, as reported for the Russian Federation, Eastern EU countries and Sardinia (Oļševskis *et al.* 2016, Vergne *et al.* 2016, Sanchez-Cordon *et al.* 2018), especially if free-ranging pigs are involved (Franzoni *et al.* 2020, Tao *et al.* 2020). The wild boar population would therefore contribute to the spread and maintenance of the infection, and represent a possible epi-bridge among Backyard farms. Iglesias and colleagues (Iglesias *et al.* 2018) analysing the spread of ASF in the Russian Federation show that, after an initial phase, the disease shows a behaviour as if wild boars and pigs were a single population. Regarding the average distance from rendering plants, the South Italy returned two different results for the two scenarios, it shows a quite low value for the domestic pig scenario while in the wild boar scenario the value increases strongly (Figure 10). This suggests that the spatial distribution of the rendering plants is strongly related to the spatial distribution of the farms, as expected, and that pig farms and the distribution range of wild boars show some type of spatial segregation, which might hinder interspecies spread infection.

Northern Italy - high number of pigs

Northern Italy (which includes both the macro-areas of the North Italy and the Po Valley) will face the highest number of pigs involved, alongside the lowest number of farms for both domestic pigs and wild boars simulation sets. In these macro-areas, there is the highest percentage of large farms (Fatteners) representing the majority of the pig population involved. Bellini and colleagues (Bellini *et al.* 2020) conducted a study on the risk of ASF introduction in Lombardy (the region belongs to both the Alpine and the Po Valley macro-areas): they found that 109 municipalities with 297 pig farms were at very high risk. These farms were selected for targeted surveillance aimed at early detection of ASF, in order to prevent its further spread.

The main focus of the disease eradication effort will be on pigs culling and carcasses disposal, which should also take into account the possible overloading of rendering plants capacity. Developing an application-ready plan for carcasses disposal that takes into account rendering capacity will mitigate the risk of safe disposal system failure. Rendering facilities are widely available for these areas, however, the high average number of pigs per farm could cause the disposal system to become overloaded if several large farms are infected at the same time. To reduce this risk, high levels of biosecurity measures are required to prevent infection from spreading among farms. In fact, large farms apply protocols to prevent disease transmissions, such as disinfection of truck tires, gears, boots and farming tools and are required to record all animal movements, which can help trace the origin of the disease and potentially contaminated products exported from the farm With regard to the average distance from rendering plants, the Po Valley, considered only for the first scenario, returned the lowest value. However, it should be noted that the distances to the rendering plants were calculated as straight lines, ignoring the orography of the territory which can have a strong impact on the actual distance or the time needed to reach the rendering plants. This is particularly true for the Alps, while for the Po Valley and the North Italy, being mostly flat areas, our straight-line distance calculation can be considered as a good approximation for the real distance value.

Central Italy

Central Italy represents the worst-case scenario, as many farms and pigs are involved in both domes-tic pigs and wild boar infection scenarios, and the lack of disposal capacity will challenge any eradi-cation process by increasing costs, time and labour. The geographical distribution and abundance of wild boars in this area are among the highest in Europe (Pittiglio *et al.* 2018), creating a potentially explosive situation. In fact, infection reaching the wild boar population would strongly complicate the eradication of the disease, which could even become endemic and spread − through the wild boar population − to the whole country. Furthermore, Central Italy returned the highest values of the mean distance to rendering plants for both scenarios because rendering plants are simply not present in this macro-area (Figure 2).

Conclusions

Our simulations outline two possible outcomes for an outbreak of ASF in Italy, geographically identified. If the outbreak were to occur in the Northern part of the country − the Alps, the North Italy and the Po Valley − it would involve a large number of pigs and affect the production system with strong economic consequences. In fact, in this area, we find most of the pig production system (e.g. pig farms, slaughterhouses, charcuterie factories) which in the event of an epidemic would undergo great stress or even a crisis. On the contrary, the veterinary services should be able to manage the outbreak without facing a crisis, since rendering plants are able to dispose of carcasses without being overloaded.

If the outbreak were to occur in the macro-areas of Central or the South Italy, it would involve a large number of farms, probably scattered throughout the territory. This would require a great effort on the part of the veterinary services, which would probably face a crisis trying to keep the restricted area monitored and under control. The pig production system would not be greatly affected by the epidemic, but the pig industry would still be economically affected by the national blockade on the export of the products.

A recent study calculated the probability of an ASF outbreak for all European countries still free of ASF, and for Italy, the estimated probability was between 0-0.1 (Taylor *et al.* 2020, probabilities calculated for the year 2019 based on 2018 data), with the most likely reason for the outbreak being legal trade in infected pigs (or pork meat). Although this is a low probability, more than half of the estimated potential ASF outbreak locations in that study were in the Central or in the South Italy, the two macro-areas with the highest density of Backyard farms, and this could cause cascading events leading to a wide and uncontrolled spread of the disease. Therefore, although the probability of an outbreak of ASF is low, we suggest an updating of the contingency plan to deal with the emergency, taking into consideration the characteristics of the local farming system, together with the availability of rendering plants and their capacities.

Acknowledgements

Authors would like to thank the Banca Dati Nazionale of the Istituto Zooprofilattico dell'Abruzzo e del Molise 'G. Caporale' for sharing most of the data included in this study.

Giorgia Baiocchi received a research grant from the project: Miglioramento delle strategie e degli strumenti di controllo della Peste suina africana in Italia (PSRC1/2018) funded by Ministero della Salute and leaded by Istituto Zooprofilattico dell'Umbria e delle Marche 'Togo Rosati'.

References

Bellini S., Scaburri A., Tironi M. & Calò S. 2020. Analysis of risk factors for African Swine Fever in Lombardy to identify pig holdings and areas most at risk of introduction in order to plan preventive measures. *Pathogens*, **9** (12), 1077.

Bellini S., Casadei G., De Lorenzi G. & Tamba M. 2021. A review of risk factors of African swine fever incursion in pig farming within the European Union Scenario. *Pathogens*, **10** (1), 84.

Bellini S. 2021. The pig sector in the European Union. Understanding and combatting African Swine Fever: a European perspective. Wageningen Academic Publishers, 183-195.

EFSA Panel on Animal Health and Welfare (EFSA AHAW Panel), Nielsen S.S., Alvarez J., Bicout D., Calistri P., Depner K., Drewe J.A., Garin-Bastuji B., Gonzales Rojas J.L., Michel V., Miranda M.A., Roberts H., Sihvonen L., Spoolder H., Stahl K., Viltrop A., Winckler C., Boklund A., Bøtner A., Gonzales Rojas J.L., More S.J., Thulke H.-H., Antoniou S.-E., Cortinas Abrahantes J., Dhollander S., Gogin A., Papanikolaou A., Gonzalez Villeta L.C. & Gortazar Schmidt C. 2019. Scientific Opinion on the risk assessment of African swine fever in the south-eastern countries of Europe. *EFSA Journal*, **17** (11), 5861.

European Commission (EC). 2015. Working document - Strategic approach to the management of African Swine Fever for the EU-SANTE/7113/2015-Rev 12. European Union DG Sante, Brussels, Belgium.https://ec.europa.eu/food/sites/food/files/animals/docs/ad_control-measures_asf_wrkdoc-sante-2015-7113.pdf.

European Commission (EC). 2010. Working document - Guidelines on surveillance/monitoring, control and eradication of classical swine fever in wild boar. SANCO/7032/2010-Rev 4. European Union DD Sanco, Brussels, Belgium. https://ec.europa.eu/food/system/files/2016-10/ad_cm_csf_guidelines-7032-2010r4.pdf.

Franzoni G., Dei Giudici S., Loi F., Sanna D., Floris M., Fiori M., Sanna M.L., Madrau P., Scarpa F., Zinellu S., Giammarioli M., Cappai S., De Mia G.M., Laddomada A., Rolesu S. & Oggiano A. 2020. African Swine Fever circulation among free-ranging pigs in sardinia: data from the eradication program. *Vaccines*, **8** (3), 549.

Iglesias I., Montes F., Martínez M., Perez A., Gogin A., Kolbasov D. & de la Torre A. 2018. Spatio-temporal kriging analysis to identify the role of wild boar in the spread of African swine fever in the Russian Federation. *Spatial statistics*, **28**, 226-235.

Monaco A., Franzetti B., Pedrotti L. & Toso S. 2003. Linee Guida per la gestione del Cinghiale. Ministero delle Politiche Agricole e Forestali (MIPAF) – Istituto Nazionale per la Fauna Selvatica (INFS). https://www.isprambiente.gov.it/it/pubblicazioni/manuali-e-linee-guida/linee-guida-per-la-gestione-del-cinghiale.

World Organisation for Animal Health (OIE). 2021. Terrestrial Animal Health Code. 29th Ed. https://www.oie.int/en/what-we-do/standards/codes-and-manuals/terrestrial-code-online-access/.

Oļševskis E., Guberti V., Seržants M., Westergaard J., Gallardo C., Rodze I. & Depner K. 2016. African swine fever virus introduction into the EU in 2014: experience of Latvia. *Res Vet Sci*, **105**, 28-30.

Oļševskis E., Schulz K., Staubach C., Seržants M., Lamberga K., Pūle D., Ozoliņš J., Conraths F.J. & Sauter-Louis C. 2020. African swine fever in Latvian wild boar - A step closer to elimination. *Transboundary Emerg Dis*, **67** (6), 2615-2629.

Pittiglio C., Khomenko S. & Beltran-Alcrudo D. 2018. Wild boar mapping using population-density statistics: from polygons to high resolution raster maps. *PloS ONE*, **13** (5), e0193295.

Sánchez-Cordón P.J., Montoya M., Reis A.L. & Dixon L.K. 2018. African swine fever: a re-emerging viral disease threatening the global pig industry. *Vet J*, **233**, 41-48.

Sauter-Louis C., Forth J.H., Probst C., Staubach C., Hlina A., Rudovsky A., Holland D., Schlieben P., Göldner M., Schatz J., Bock S., Fischer M., Schulz K., Homeier-Bachmann T., Plagemann R., Klaaß U., Marquart R., Mettenleiter T.C., Beer M., Conraths F.J. & Blome S. 2021. Joining the club: first detection of African swine fever in wild boar in Germany. *Transboundary Emerg Dis*, **68** (4), 1744-1752.

Taylor R.A., Condoleo R., Simons R.R., Gale P., Kelly L.A. & Snary E.L. 2020. The risk of infection by African swine fever virus in European swine through boar movement and legal trade of pigs and pig meat. *Frontiers Vet Sci*, **6**, 486.

Tao D., Sun D., Liu Y., Wei S., Yang Z., An T., Shan F., Chen Z. & Liu J. 2020. One year of African swine fever outbreak in China. *Acta Tropica*, **211**, 105602.

Vergne T., Korennoy F., Combelles L., Gogin A. & Pfeiffer D.U. 2016. Modelling African swine fever presence and reported abundance in the Russian Federation using national surveillance data from 2007 to 2014. *Spatial and Spatio-temporal Epidemiology*, **19**, 70-77.

Vergne T., Guinat C. & Pfeiffer D.U. 2020. Undetected circulation of African swine fever in wild boar, Asia. *Emerg Infec Dis*, **26** (10), 2480.